NASA

THE COSMONAUT AS RESEARCHER

ANNOTATION

This pamphlet discusses in popular form the studies performed by cosmonauts on spacecraft. The possibilities which have opened up for science due to experiments carried out directly in space are discussed, as well as certain interesting results already obtained from the flights of cosmonauts. The cosmonaut profession and flight training are examined in detail. Future trends in the development of manned space technology are briefly investigated.

The pamphlet is designed for a wide circle of readers who are interested in the problems of human space flight.

NASA

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Introduction

Space exploration and the conquest of space is of value for all mankind. Space navigation is not only a new branch of science, it enters decisively into the life of every man as a clear manifestation of the inexhaustible possibilities of human intelligence. /3***

Artificial earth satellites now serve the national economy reliably — collecting and transmitting to Earth meteorological information necessary for the formulation of long-range weather forecasts; tracing solar phenomena and warning of adverse consequences of these phenomena; providing global communication and extra-long range telecommunications; aiding in the search for minerals; detecting forest fires, etc.

Spacecraft achieving flights to the Moon, Mars and Venus have extended the possibilities of scientific exploration of the solar

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system, complementing former methods of investigation with a fundamentally new one — direct study of planetary material. New data have already been obtained about conditions on the surface of the Moon, Venus, and Mars, the physical and chemical characteristics of lunar soil, the atmospheres of Mars and Venus, the circumterrestrial space and space around the Moon have been more accurately determined. The effect of space navigation on production is gradually increasing and intensifying. Contemporary industry is undergoing serious reorganization in connection with the development of such complex technology as spacecraft and instrumentation placed on them.

Space navigation also has a highly beneficial influence on such areas of social activities as public health, education, culture. Highly refined means of medical monitoring developed for the crews /4 of manned spacecraft can be and already have been applied successfully in medicine. There is no doubt that an enormous role in disease prevention will be played by the new direction initiated in space medicine — forecasting the status of the healthy human organism for several weeks and even months ahead.

Experience in applying various training apparatus, panels, and test stands accumulated in preparing cosmonauts for flight can be effectively applied to education, particularly in the professional-technical instruction and selection system.

Investigations carried out on manned spacecraft and stations have been particularly varied and productive. This has been assisted by favorable conditions for accomplishing such investigations (contemporary manned space technology provides for the installation of the most sophisticated scientific apparatus and instrumentation having advanced data-handling capabilities, accuracy, and reliability), as well as by highly qualified specialists — the cosmonaut-researchers — taking part in the experiments. Man, by his own activity, has provided not only high technical reliability, but also the highest achievements in new directions in science and practice. Space navigation has now become one of these directions. Thus, interest in space research has increased sharply in the widest masses of the

population, and the cosmonaut profession has become one of the most popular, attracting the close attention of many people, especially children. The features of cosmonaut work and the conditions of their activities in space, however, are relatively little known to the general reader.

Recently, the sphere of activity of the cosmonauts during space flights has sharply expanded. In many respects, this is explained by the fact that ever greater numbers of branches of science and national economy have advanced proposals for space experiments on manned spacecraft. Since many experiments are performed for the first time, a significant role in the flight programs of the cosmonauts is alloted to developing techniques for performing these experiments — a largely creative process. Since the flight of each crew into space generally opens a new page in the utilization of /5 space, the cosmonauts are often obliged to solve new, most unexpected problems requiring independent solutions not provided for in the flight plan. Thus, cosmonaut activity is very distinctive. More than in any other activity, the trivial can be interwoven with the heroic, the usual, well-carried-out operations — with quite unusual actions not encountered previously. It is natural that, in the selection and preparation of cosmonauts, an important role is played by their personal qualities, constant preparedness for independent work, aptitude for handling the most unexpected situations under pressures of time and complex circumstances.

Pilot-cosmonaut, candidate of technical science V. I. Sevast'yanov has well stated the characteristics of the cosmonaut's work: "The cosmonaut profession necessarily has two sides today. The cosmonaut must be an analyst, that is, in flight he must control the operation and carry out tests on the spacecraft and its onboard systems to ensure future development of space technology, and, at the same time, he must be a researcher in order to extract valuable information from the surrounding space, atmosphere, and surface of the Earth" [1].

Actually, by the nature of his work the cosmonaut is always an analyst, always a researcher. The launch of each Soviet spacecraft has been associated with the beginning of a new stage in space exploration; only the specific problems placed on the crew, their number and content have differed. Sometimes, one central problem is designated in the flight program, whose solution implies the emergence of space science and technology into a qualitatively new stage. These were: the first manned flight into space, the first "space walk", the first group flight on the "Voskhod-1" spacecraft, the first rendezvous of manned spacecraft, etc. But in each flight, the cosmonauts have solved more problems of all kinds. Their number and variety have increased with time and have required the production of multi-stage spacecraft and long-term orbital stations. However, in the program of each manned craft, one feature has remained unchanged — the cosmonauts have had to solve problems for the first time, tasks /6
have been put before them which have never been performed before. And finding the solution of these new, unknown problems has required independence and creativity with consideration of changing operating conditions, i.e., first and foremost, research activity and study of the unknown is advanced in the work of the cosmonauts.

Even such "ordinary" processes as eating, physical exercise, and hygienic procedures are for the cosmonaut an investigation of new diets, new foodstuffs, new techniques. The same applies also to the maintenance of the onboard systems of the spacecraft. Space technology is continuously improving, and sometimes the cosmonaut, having studied one form of instrumentation as a back-up, later in an independent flight operates on other instrumentation, investigating its quality, convenience, and reliability.

In this pamphlet, we will try to describe the content of research work carried out by cosmonauts in flight, the most important directions of research performed on board manned spacecraft, i.e., those forms of activity which to a significant degree define the cosmonaut profession in our time.

Research on Manned Spacecraft

It is difficult even to merely list all the problems whose solution can be achieved on manned spacecraft — such a large number of questions await their solution in space. For convenience of analysis, all the work of the crew is divided into several groups in compiling the flight program: scientific programs; problems to be solved in the interest of the national economy; problems of inspection, control, and servicing of onboard systems; self-servicing work. /7

In compiling the in-flight program for the crew, a comparison is made of the relative importance of various forms of cosmonaut activity with an estimation of the assumed scientific or economic effect to be obtained by the solution of one or another problem. Of course, there is no general rule for uniquely compiling the optimum program. However, definite principles can be formulated, which can be used in developing projects of new space techniques and provide the best results from manned space flights for a large time interval (say, for 10 or 20 years).

These principles include the following:

gradual and systematic solution of the basic problems of space science (such as developing the laws of conversion of energy and other forms of matter in the universe; investigating the origin and evolution of galaxies, stars, and planets; detecting extraterrestrial forms of life; investigating the conditions for the existence of terrestrial forms of life in space and on celestial objects; etc.);

creation of the scientific and technical bases for subsequent work in space (development of refined spacecraft and long-term stations, development of energy for flight into deep space, creation of /8
long-term life-support systems of varying degrees of automation, etc.);

provision for a succession of space operations from one spacecraft to another;

solution primarily of problems in working out new space technology (multistage orbital stations, manned craft for interplanetary expeditions, promising rocket-carriers, highly sophisticated onboard systems, reusable spacecraft, etc.) and problems of national economy to achieve the greatest economic advantages even now (meteorological problems for improving long-range weather forecasting, oceanological problems for developing ocean fisheries, problems of agriculture and forestry, etc.).

In the initial stages of the development of space technology, testing new models of systems and instrumentation of spacecraft and the solution of medical and biological problems of manned space flight are of the most important value. Manned spacecraft and their onboard systems are unusually complex and sophisticated devices with very diverse operations which take place under the unusual conditions of space, which are extremely complicated or generally impossible to reproduce on earth. Thus, many technical solutions, designs, and processes specified by designers of spacecraft can be definitely verified only after thorough tests under the actual conditions of space flight. It is evident that such tests can be performed most thoroughly and reliably by man — specialists in the respective systems. Testing a new technology is also an important stage in the creation of future sophisticated and reliable space systems intended for forthcoming prolonged space flights — in the development of long-term orbital stations or for expeditions to other planets.

Among the medical studies, the basic ones have been: establishment of the basic possibility of vital activity and operating efficiency of man in space, determination of the best conditions in pressurized cabins and the creation of efficient means for monitoring the health of the cosmonauts. These problems have now been solved successfully, and the first stage in medical research on /9
manned space flight has been the problem of determining the limiting adaptation possibilities of the human organism to conditions of weightlessness and the reaction to terrestrial gravitation after the return from space.

The creation of long-term manned orbital base-stations projected in the immediate future is the first stage in the implementation of prolonged programs of scientific studies under space conditions. Among the scientific problems facing the crew of an orbital base, two large groups can be distinguished. Problems associated with observations beyond the Earth and celestial objects in spectral regions inaccessible in surface observations are in the first group. Problems whose solutions in essence broaden the possibilities of scientific laboratories on Earth belong to the second group. These are: study of the properties of materials under space conditions (weightlessness, ultrahigh vacuum, intense radiation); study of the technological processes of joining materials (welding, cementing, bonding by diffusion in the solid phase); study of the interaction processes of ultrahigh-energy elementary particles; application of space conditions for medical purposes; etc.

There are also problems connected with the most efficient and economical disposition of scientific apparatus on long-term manned stations, the unification of its elements and systems, the creation of methods for the most effective operation of the stations in the interests of science and the national economy.

Man and Automatic Equipment in Space

One of the most discussed questions in contemporary space science is the necessity of direct participation of man in space research and the distribution of tasks between manned and automated systems. There are different opinions and approaches to the solution of this question. The Swedish scientist, Nobel-laureate H. Alfvèn, has expressed the opinion [2] that, if scientific observations were /10
the only goal of space flight, then sooner or later all the problems of space science would be solved by automatic means.

However, manned space flight includes a large number of important aspects. Apart from the collection of scientific information, such flights represent a qualitatively new stage in human development,

in mastering the forces of nature. On one hand, the escape into space has allowed man not only to solve complex problems posed by terrestrial science, but also to make new discoveries, to reveal new scientific problems. On the other hand, the penetration of man into space is only a step on the way to its settlement and utilization, about which K. E. Tsiolkovskiy already has spoken very persuasively.

The advantages of a human investigator over automated instruments and robots are obvious. Man has the capability of deep analysis, he can select rapidly and qualitatively from a large flow of information the most valuable portion, and more important, can be directed in unfamiliar situations, to assume solutions based not only on information received during flights and a given program of operation, as can be done automatically, but also based on his own individual knowledge and experience, both special scientific as well as general.

The well-known Soviet scientist, associate member of the AN SSSR K. Ya. Kondrat'yev, who has studied intensively the problem of analyzing scientific information obtained from space by automatic artificial Earth satellites and with the help of the crews of orbital spacecraft, has noted that in conducting space research several facts necessitate the participation of man and require the inclusion of cosmonaut-specialists of various scientific and technical disciplines in the crews of future orbital stations. K. Ya. Kondrat'yev has correctly pointed to the following:

1. Necessity for the conscious selection of objects for study. The specialist, upon interrogation from Earth or independently, can make such a selection, which is particularly valuable for increasing accuracy and operational efficiency.

2. Possibility of ensuring the most favorable conditions for photographing terrestrial objects. /11

3. Possibility of testing, inspecting, monitoring, and even repairing complex scientific apparatus [3].

There is a significant number of experiments and various operations in space for whose performance man is quite necessary. Such are, for example, medical studies, which are practically impossible without man, a wide range of psychological studies of various types. Experiments in engineering psychology, development of systems and methods of manual control are impossible without man. Experiments in visual navigation using celestial objects belong to this same group. Repair of equipment on board spacecraft is practically impossible to imagine without human participation — replacement or restoration of faulty components and units, and also work on the outer surface of the craft in space.

In a number of investigations which can be automated in principle, a qualitatively new tone is acquired with human participation. Thus, the experienced investigator selects the most important information, while the robot records everything falling into its "field of view". Observations of the upper layers of the Earth's atmosphere and of various little-studied regions of the Earth's surface are related to such operations. Participation of specialists is very valuable in the adjustment and alignment of research apparatus in finding their optimum operating conditions and in selecting all kinds of exchangeable attachments, etc. Apparatus adjusted by specialists subsequently can be used successfully in automatic operation, but man is very useful for its repair. On the negative side, the use of cosmonauts in various space operations introduces definite difficulties and additional problems which do not arise in automated flight. Above all, the necessary conditions for normal human activity and high efficiency on board the spacecraft must be provided.

One of the important conditions for effective human activity on Earth as well as in space is a definite, rather large, free space for performing working operations, relaxation, etc. Thus, on the first /12 Soviet spacecraft "Vostok" the free volume was 5 m^3, on the "Soyuz" craft — 15 m^3, and on the multistage orbital station "Salyut" — about 100 m^3. The volumes on the American manned craft are analogous: on the "Mercury" — 3 m^3; "Gemini" — 10 m^3; "Apollo" — 20 m^3.

It is natural that manned spacecraft (SC) are significantly larger than automated apparatus and have correspondingly significantly greater weight. The weight of special life-support systems intended to provide the cosmonauts with oxygen, drinking and sanitary-hygienic water and food, as well as the disposal and utilization of various waste products of the crew, is added to the weight of manned SC. As is well-known, a human with an average weight of about 70 kg requires daily about 600 gm of oxygen, 600 - 800 gm of dry food and 2 - 2.5 gm of drinking water. In addition, the human requires 5 - 10 gm of water for sanitary-hygienic needs in prolonged space flights. In the process of human activity, about 500 gm of carbon dioxide, 2.5 - 3 gm of water (perspiration, etc.), and 100 - 200 gm of solid waste are generated.

There are a large number of possible organizational plans for life-support systems. The simplest plan is the use of stockpiles of water, food, and oxygen in pure or chemically bound form and the collection and storage of wastes. The main disadvantage of such a system is the direct dependence of the system weight on the duration of the flight, so that for a flight of about 30 days, the weight of such a life-support system already exceeds the weight of the crew. A more sophisticated plan provides for the recovery (regeneration) of part of the raw materials required by man (oxygen, water) from the generated products. Comparatively small stockpiles of materials are required for such a system, but the inherent weight of the system is rather great because of the complex apparatus. Thus, for short-term flights its weight is even greater than the weight of the stockpile system. Regenerative systems of varying degrees of closure will be suitable for use in the future of spacecraft intended for flights lasting several months or years. The selection of a certain /13
life-support system is the problem to be solved by the designers in developing spacecraft. In any case, a significant weight expenditure is necessary for any life-support system for manned space flight.

Since the cost of developing and launching heavy manned SC is still rather high at present, it is clear that its very frequent use is economically disadvantageous. For the solution of a number of

problems, the use of manned SC not only has no advantage, but is simply impossible. For example, it is necessary to send automated equipment to study space about the Sun, which is characterized by an extremely high thermal flux, or to investigate high-energy cosmic radiation, since these conditions are hazardous for the human organism. It is also necessary to begin with automatic means to investigate any unknown space factor, such as, for example, the preliminary study of conditions on the surface of the Moon or planets of the solar system. Thus, automatic apparatus will be the first travelers in flights to the Moon, Venus, and Mars, paving the way for the cosmonauts.

The distribution of the spheres of influence of automated and manned space apparatus in general will have, approximately, the following form. At the very first stage in investigating any celestial object or space phenomenon, automated apparatus (one or several, depending on the complexity of the problem) will be launches for preliminary study and for working out the appropriate techniques. Then expeditions of cosmonauts will be sent with the participation of scientific specialists for deeper and more thorough study. These investigations will subsequently develop into a stage of deeper study with various automatic and manned means.

It is obvious that even on the manned spacecraft itself not all the work must be done by the crew. The manned spacecraft is a "man - machine" system whose efficiency depends to a great degree on the proper distribution of functions between man and auotmation. Thus, /14 in the design of spacecraft, the tasks to be performed on it will be distributed between the crew and automatic equipment, and the basic requirements of the cosmonauts will be formulated from the point of view of professional skills and qualities which they should acquire in the flight preparation process.

There are various points of view about the duties of the crew of a spacecraft. Disagreement is especially great about the participation of the cosmonauts in controlling the onboard systems. At first, when the experience in manned space flight was very sparse,

the thought was often expressed that all or almost all control functions should be performed automatically, and the cosmonaut could take control only in emergency situations. The other extreme is the tendency for the cosmonaut to perform as many control tasks as possible, and the automatic devices remain as back-up. It is difficult to agree with either extreme view. On the one hand, it is incorrect to view the crews of manned spacecraft as merely passengers taking no part in the control. But to place all the responsibilities for this control entirely on the cosmonaut — as, for example, on the pilot of an airplane — is also impossible. Even in contemporary aviation, automation plays an important role in flight control, and the number of problems whose solution requires quick response and high precision is magnified in space flight.

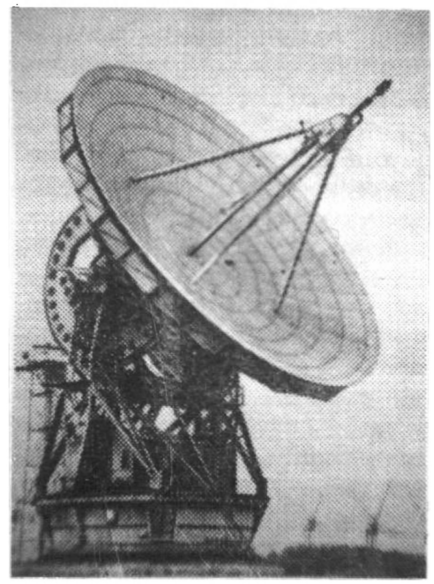

Figure 1. Antenna for deep-space communication

In actual space flights, the functions of the crew in controlling the SC are constantly changing, and a tendency has been observed to broaden the range of human operation with intensification and elaboration of problems and operations. Actually, from the beginning, cosmonauts interfered in the operation of onboard systems only in cases of any failures in the automation. American astronauts encountered various failures and malfunctions in the onboard systems as early as the first of their manned "Mercury" satellites. Thus, in the flight of the first American astronaut John Glenn in "Friendship-7", instruments indicated before the firing of the braking engine module (BEM) that the heat shield fastening system was loose. There was a danger that the heat shield would fall off after separation of the BEM. The astronaut made the decision not to separate the BEM after its operation, and the descent took place with it. /15

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Greater difficulties occurred with Cooper flying on the "Mercury MA-9" craft, who had to eliminate a malfunction in the automatic device controlling the sequence of operations for descent from orbit. The trouble was aggravated by the fact that the malfunctioning device continued to operate giving incorrect commands and prevent the astronaut from taking control himself. But, nevertheless, the astronaut and the personnel of the ground stations, although with great difficulty, were able to find a method to eliminate the emergency situation.

Subsequently, system failures on the other American spacecraft "Gemini" and "Apollo" forced the astronauts to remain in constant readiness either to disconnect malfunctioning instrumentation or even to carry out repairs.

On manned Soviet craft, cosmonauts first encountered automation failure during the flight of "Voskhod-2", when the automatic landing control system failed to fire. The craft commander, pilot-cosmonaut P. I. Belyayev, analyzing the situation, oriented the craft manually and fired the BEM at the calculated time.

The firm conviction has been reached at present that the participation of cosmonauts in the control of onboard systems and in their maintenance for preventive inspection and repair significantly increases the general reliability of the systems and, consequently, /16 increases flight safety and effectiveness in completing the given program. Thus, in the design of contemporary and future manned spacecraft, such crew activity is planned and included in the flight program. Calculations and ground experiments indicate that such an approach to crew tasks has particularly great advantages in the case of long-term orbital space stations and interplanetary craft for flights lasting several months or years.

The feasibility of human participation in performing scientific experiments on board spacecraft is determined by many reasons. For example, in investigations involving observations of various objects on the Earth, important roles are played by: the sharpness of the

view, visibility conditions, degree of preparation (training) of the cosmonaut, the presence of characteristic distinguishing features of the object observed. The resolving power is about one to several minutes of arc, i.e., from an altitude of 200 km one can distinguish objects 200 - 300 m in size. With favorable visibility conditions, significantly better results can be achieved. Good solar illumination and light and shape contrast with the surrounding background is very important for this. Extended objects — rivers, roads — are seen especially clearly. The preparedness of the cosmonaut plays an important role: he can distinguish much more detail in familiar localities. In particularly favorable cases, cosmonauts have seen objects only 10 - 20 m in size.

For example, in May, 1965, the American astronaut Cooper in the "Gemini-5" spacecraft reported that he could distinguish the launch pads at the American space field, airport runways, streets, and even smoke from chimneys. The Soviet cosmonaut, G. T. Beregovoy, clearly saw ocean vessels by their wake on the ocean surface. These demonstrations of human vision open up great prospects for the visual observation of terrestrial objects. For example, tectonic formations on the Earth's surface can be studied visually very thoroughly and effectively from orbiting stations. The information cited above indicates that even small fractures and faults from several tens of meters to several kilometers in size are also quite accessible to /17 visual observation from space. Likewise, visual observation from orbital stations of ice accumulations in the polar seas, of snow caps on mountains, etc., can be carried out conveniently. Evidently, it is quite possible to observe from space individual plots of vegetation in inaccessible locations, large herds of livestock, sources of forest fires.

Terrestrial Observations by Cosmonauts

Even the first flights of Soviet cosmonauts gave extremely interesting data about the Earth, its surface and natural resources, about the condition of the oceans and seas, about processes in the atmosphere. An extensive course in space science gradually developed which is sometimes called space geography. From near-Earth orbit, cosmonauts carry out various observations aiding the study of our planet and the use of its space and resources. Very many scientific and economic problems can be solved in principle significantly faster and more economically due to the participation of cosmonauts carrying out regular observations of the Earth from space. In the number of branches already having the closest ties with space technology, one can name geology, meteorology, hydrology, television, geodesy, cartography, forestry, in which the economic effect when using data obtained by cosmonauts becomes greater with each new flight of manned craft.

We shall now discuss several branches of national economic activities of cosmonauts, in which definite experience has already been accumulated, and which will certainly occupy an important place in the flight programs of future long-term orbital stations.

We begin with meteorology. There is no need to explain how important timely weather forecasts are for the national economy of a country. In addition, it is well known that even now there is much which is unclear and unresolved in this problem. It is well known that the atmosphere as a whole takes part to a significant extent in the formation and development of weather phenomena. It is the medium through which there occurs the mutual effects of pro- /18
cesses arising in regions of the Earth sometimes very far apart. Data obtained from ground meteorological observation stations do not always detect all the processes which occur in the atmosphere and affect weather formation, since the number of such stations is limited, and in a number of vast, inaccessible regions of the Earth there are very few or none at all. In addition, for weather

forecasting it is necessary to know the state of the atmosphere, not only at the surface of the Earth, but also at various altitudes.

The use of aviation and meteorological rockets has increased the overall information, of course, but it is also limited in its possibilities, and does not represent the state of the entire atmosphere. Space technology can help here. It was found that meteorological information obtained from space is not only more extensive, but also implies a new quality extremely valuable for forecasting — it gives /19

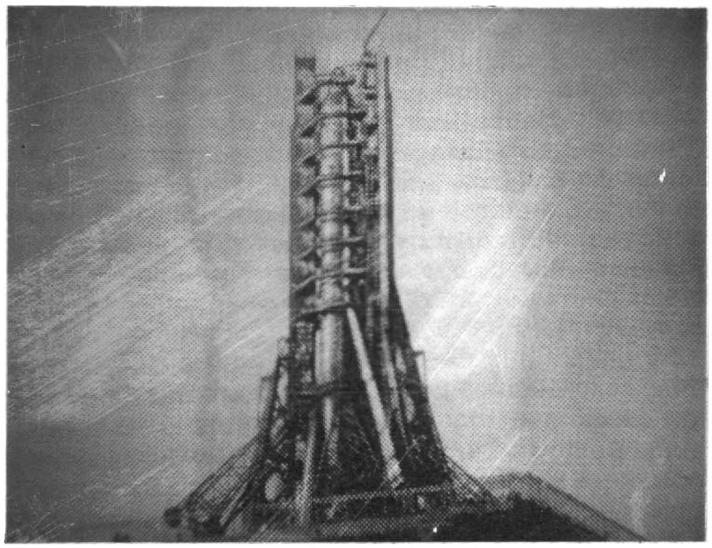

Figure 2. Rocket with "Soyuz" spacecraft at launch

a representation of atmospheric processes occurring over the whole planet. Essentially, photographs taken from space in the visible or infrared region of the spectrum are unique records of the Earth's weather. Scientists consider that the store of knowledge which could be obtained just from images from space of the Earth's cloud cover would even exceed the information obtained by any other ground-based methods. With the aid of automatic equipment placed on artificial Earth satellites, weather service is provided over television channels with extensive and very valuable information about the state of the Earth's atmosphere. However, such minute details as obtained on photographs by the cosmonauts have not been successfully obtained

by automatic methods. But some details are of significant value for detecting atmospheric processes associated, for example, with the formation of cyclones, tropical hurricanes, increased air turbulence on airline flight paths, etc.

Much experience in using space data in weather service has been accumulated over the years in which space meteorology has existed. Meteorologists have noted that the particularly valuable quality of meteorological information obtained during visual observations by the crews of manned craft and stations lies in the fact that valuable information reaches the Earth quickly, and in a form convenient for rapid application. Cosmonauts not only give the general characteristics of the observed phenomenon (size, intensity, shape, color), but also report quite accurate information on its location and direction of motion.

Meteorological observations from space were essentially started by Yu. A. Gagarin, who reported during his historic flight that not only could he easily distinguish coastlines, islands, large rivers, large reservoirs, geological features, field squares, but he could also easily see clouds and even their shadows on the surface of the Earth. These data, which were completely verified by the results of later flights of Soviet cosmonauts, served as a basis for including in the flight program for the crews of manned craft special tasks /21
from the Hydrometeorological Service in observing a number of weather phenomena. Thus, the commander of the "Soyuz-4" craft V. A. Shatalov observed, on January 15, 1969, a strong cloud vortex associated with a deep cyclone over the Atlantic off the west cost of Europe. On January 17, 1969, the commander of the "Soyuz-5" craft B. V. Volynov observed lightning flashes and a strong thunderstorm over South America. On January 18, he also saw a thunderstorm off the southwest coast of Africa. Over the Indian Ocean, Volynov observed an incipient tropical cyclone. The results of his observations were well-timed for study by meteorologists and forecasters.

Figure 3. Crews of "Soyuz-4" and "Soyuz-5": Ye. V. Khrunov, A. S. Yeliseyev, V. A. Shatalov, and B. V. Volynov

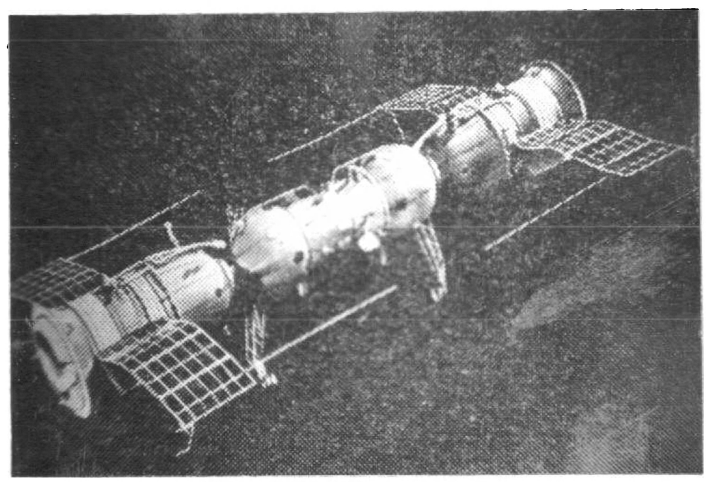

Figure 4. "Soyuz-4" and "Soyuz-5" spacecraft. Creation of experimental orbital station

Cosmonauts G. S. Shonin and V. N. Kubasov, on the "Soyuz-6" spacecraft observed the tropical strom "Jennifer" off the coast of Mexico, and the crew of "Soyuz-7" reported the generation of a cyclone off the coast of Cuba, in which they anticipated ground-based weather service by a day. On "Soyuz-9", cosmonauts V. I. Sevast'yanov and A. G. Nikolayev carried out nearly 20 meteorological observations with transmission of their data to Earth. On June 3, 1970, they detected a tropical cyclone in the Indian Ocean and transmitted its coordinates to ground services. Two days later, they observed the same

cyclone in the bay of Bengal. Dust storms were easily seen in Afghanistan and Iran, and strong thunderstorms — in Africa and in North America in the Great Lakes region. Thunderstorms were observed particularly clearly on the dark side of the Earth. /22

Figure 5. Cosmonauts A. G. Nikolayev and V. I. Sevast'yanov given an interview to journalists before the launch of "Soyuz-9" spacecraft

The complex hydrometeorological experiment performed during the 188th orbit of "Soyuz-9", in which the scientific-research craft "Akademik Shirshov", the "Meteor" satellite, and the crew of the spacecraft took part, is of interest. In the course of this experiment, simultaneous measurements were made of the characteristics of the atmosphere at various altitudes over the western part of the Indian Ocean. The automatic equipment of the "Meteor" satellite took telephotos from an altitude of 600 km. The cosmonauts made visual observations and photographs from the altitude of their orbit (230 km). At lower altitudes, recordings were made from a meteorological rocket fired from the "Akademik Shirshov". Finally, various measurements were also made at the ocean surface on the craft itself.

On June 15, A. G. Nikolayev and V. I. Sevast'yanov took a series of interesting photographs of cloudiness, several of which attracted the attention of scientific meteorologists. One of them depicted a cloud accumulation over the Atlantic Ocean, 500 km from Ascension Island, which indicated the generation of a strong tropical cyclone in this area. /23

In one of his transmissions to Earth, A. G. Nikolayev reported seeing a cyclone approaching Novosibirsk. This warning was used at

once in the operational weather service, and had a significant economic effect. A large number of meteorological observations with data transmission to Earth were made by the crew of the orbital station "Salyut". On June 19, 1971, the cosmonauts noted a strong dust storm on the southwest coast of Africa. On June 20, they discovered and photographed a cyclone in the region of the Hawaiian Islands. On June 22, they observed a cyclone in the Indian Ocean, and reported its coordinates to Earth.

The importance of meteorological data from manned orbital stations lies in their effectiveness — data arrive about the state of cloudiness over the various continents and oceans almost simultaneously, or, in any case, on the same day. In addition, the high reliability of the information received from the cosmonauts is very valuable, for example, man can distinguish thunderstorms from any other phenomenon with much greater likelihood than an automatic device. Consequently, the reports of the cosmonauts hardly ever need be checked, which, of course, save the time and equipment used by specialists on Earth. In addition, when meteorology specialists are included in the crews of manned space stations (and such a time is not far off), then the role of these stations in weather forecasting should increase even further. Experienced specialists included in the crews of orbital stations can carry out significant work on improving the present and developing new methods of weather forecasting, in addition to gathering actual data on the state of the atmosphere in various regions of the Earth. Cosmonauts observing the surface and atmosphere of the Earth can effectively recognize developing atmospheric and oceanic phenomena, and can give timely warnings /24
about them to the ground weather service.

Advance information is particularly important about phenomena having the nature of natural disasters — cyclones, hurricanes, typhoons, waterspouts, dust storms, tsunamis. A few words about predicting tsunamis — gigantic ocean waves 20 - 30 m in height, formed as a result of underwater earthquakes or volcanic eruptions. They produce inundation and terrible destruction along the coasts.

Particularly great damage was produced by a tsunami along the Pacific coast of the USSR. Scientists have calculated that destructive tsunamis have attacked the cost in this region an average of every three years during the past 20 years, and weaker ones are observed yearly. Losses to the national economy due to tsunamis have been estimated at millions of rubles; thus, timely warnings about them are very important. Contemporary methods for tsunami forecasting are poorly developed, and have low reliability. The time which is available for the population to take necessary measures is now 10 - 40 minutes. It is obvious that in such cases, increasing the time reserve by even a few minutes is of very great value. If it proves to be possible to determine the moment of tsunami formation visually from a space station, this offers a time reserve up to 1 - 2 hours.

Both the systematic daily observations of cloudiness and the surface of the oceans and dry land, and also periodic surveys of the Earth's surface once or twice a month, are of great value in space weather service. The organization and frequency of meteorological observations from an orbital station can be quite varied. Some forms of observation are most valuable for short-term, others — for long-term weather forecasting. The picture observed by the cosmonauts can be taken visually or photographically on still and movie film. In the later case, information from the film can be transmitted at once to Earth for processing. Collection of the meteorological information occurs almost automatically, but under the control of the cosmonaut. He selects which part of the visible picture needs to be taken, determines the best photographic scale, spectral region, and form of the photograph (still or movie, black-and-white, or color film, spectral region in the case of spectrozonal film). Part of the pictures the cosmonaut can transmit to Earth; the rest he cannot transmit. This relieves the data transmission telemetry channels (which in itself is of great value) from the station to Earth, and ensures transmission of the most valuable data. /25

All the above indicates that the economic effect of including data obtained continuously from space in the weather forecasting service can be very great.

American specialists have estimated that increasing the accuracy of long-term weather forecasting and the early warning of the time and place of natural disaster formation with the help of space techniques will save about 2.5 billion dollars per year to the economy. This total combines separate economic effects in various areas. They calculate that improved hurricane forecasting would save about one billion dollars per year in the construction of new buildings, 500 million dollars due to timely protection of fuel stocks and energy systems, 500 million dollars due to timely crop salvage, and 400 - 500 million dollars due to the preservation of livestock products, herds of farm animals, etc. [6]. The totals are impressive. And this is for just one country!

Thus, the following basic directions of cosmonaut activity in the interests of meteorology have already been planned:

effective notification of ground services about the visual picture of the terrestrial cloud cover;

development of techniques for recognizing weather-forming factors and processes;

visual study and recording of the state of the atmosphere at high altitudes

development of the relationships of atmospheric processes, study of the dynamics of their changes, classification, compilation of standard catalog, etc. Of course, cosmonauts can observe various objects on the Earth's surface. For various branches of the national economy, it is important to know the current boundary of melting snow, the dimensions of flooded territory caused by overflowing rivers, areas of lakes, artificial seas and reservoirs. Agriculture, /26
forestry, hydrology, fisheries, power engineering, and other branches are interested in these data.

In June, 1970, the attention of specialists was drawn to the reports of the Soviet cosmonauts A. G. Nikolayev and V. I. Sevast'-yanov from "Soyuz-9" that they had twice observed snowfall and its melting over a vast territory in southern Chile and Argentina and in the area of Tierra del Fuego. These data suggest the interesting possibility of improving the precipitation observation service by using data obtained from the cosmonauts.

Among the possible methods for obtaining information about objects located on the Earth's surface, photographing these objects from space is presently the most valuable. As scientists have stated, the high image resolution and the possibility of obtaining color photographs or photographs in individual narrow spectral regions have acquired exceptionally important value for detailed interpretation of space photographs for a wide group of earth sciences, and also geobotany, agrobiology, and other research. The practice of space photography has shown that photographs of the Earth taken by the cosmonauts satisfy these requirements very well.

Color photographs of any portion of the Earth's surface covered with more or less fine details can tell the specialist a great deal. Even an inexperienced person can easily distinguish by color, for example, a snow-covered area from a freshly-plowed field or a green coniferous forest from the yellow-red autumn deciduous. If the image is considered not in the visible but in other spectral regions of the radiation from the surface, data with even more valuable properties can be obtained. For example, temperature differences on the Earth's surface can be determined from an image in the infrared. Such images are essentially thermal maps of a locality. Obtaining images of Earth with devices sensitive to thermal radioemission (the so-called passive radar method) is even more promising than color photography, since thermal radioemission passes freely through /27 clouds and, thus, photographs can be taken even with solid cloudiness.

The more diversified the apparatus recording the various spectra of radiation from the Earth, the more extensive the inforamtion about its surface. With the help of such apparatus, one can obtain

spectrograms — photographs of portions of the Earth's surface in a strictly specified frequency range.

Of course, for this purpose, ordinary photographic equipment will not do. It is necessary to have a special device — a spectrograph recording the object brightness at a definite wavelength of the radiation emitted from the surface of the Earth. If the wavelength taken by the device varies, then several photographs of the same object in different light are obtained. It is found that each zone of the terrestrial surface has its own reflection spectrum — forest, steppe, stony desert, sand dunes, lakes, rivers, etc. With the help of spectra, one can investigate the dynamics of the change of snow cover in mountains and on plains, study the distribution of ice in the polar seas, the temperature of the ocean surface, ocean currents, the distribution of vegetation, and the state of various agricultural cultivations. Of course, for the total realization of the possibilities in using space spectral photographs, one still has to solve a whole series of problems. One is, for example, to obtain a file of standard spectra for facilitating the identification of images obtained from space. For this, it would be most effective to carry out complex experiments with the simultaneous recording of spectra obtained as a result of ground, aircraft, and space observations over portions of the surface with well-studied spectral characteristics. Such a complex experiment was performed, in particular, during the flight of "Soyuz-9", when photographs were obtained of the so-called polygonsections in the regions of the northern Caucasus, Caspian and Aral Seas, Kazakhstan, western Siberia. An analogous experiment was also performed by the crew of the orbital station "Salyut". The coastal regions of the Caspian Sea were used as the polygon.

Further, with increasing experience and the necessary data on standard spectra of the Earth's surface, new possibilities open up for agriculture with the help of information coming in from the space stations. Even now, there is no doubt of the possibility, in principle, to determine from space the average degree of crop ripeness and to estimate the harvest in large masses of fields. One can /28

even detect with spectra, portions with diseased or pest-infested plantings. Of course, much work has to be done to develop the relationships of spectral changes in crops, the spectral differences between cultivated crops and weeds, and to develop the necessary apparatus. In principle, the day is not far off when various types of agricultural work can be performed at a time determined by consultation with the crews of orbital stations. It is likely that such agricultural organization is possible not only within a single country, but will be used with other states — to begin with, the Socialist countries — participants of the CMEA.

The crew of an orbital space station can solve very important problems in forestry. A particularly acute problem here is the prevention of forest fires as a result of which hundreds of thousands of hectares of forest are irrevocably lost. Significant material means are spent to prevent forest fires. As in all fires, forest fires are difficult to extinguish when they envelop large areas. Thus, the basic problem of fire prevention is early warning, and determining the area enveloped by the fire and the direction of motion of the fire. These problems can be solved by crews of orbital stations more successfully than existing means of forest preservation. The seats of fires are clearly detected from orbital spacecraft, particularly on the night side when the craft is in the Earth's shadow. For example, A. G. Nikolayev and V. I. Sevast'yanov, during the 18-day flight on "Soyuz-9", repeatedly saw fires in the Siberian taiga, forests of Africa, Australia, South America, and reported them to Earth. Analogous reports have also been made from other Soviet and American spacecraft.

The application of space techniques opens up great possibilities in ocean fishing. There is a range of problems here to be solved by cosmonauts on orbital stations, very broad and varied. This is the detection of fish habitations in the open ocean, their migrations, /29
etc. Many problems, such as compilation of fishery charts, can be successfully solved by automated satellites. However, effective information for the whole fleet or for individual groups of ships, estimates of the fish harvest in licensed regions, and work requiring

high accuracy can be effectively carried out by crews of orbital stations.

The Soviet fishing fleets now extract more than 5 million tons of fish and other ocean products from all the seas and oceans of our planet. The catch increases each year. For this, fishing vessels are obliged to go into open water areas ever farther from shore and require ever greater time to get there. It is obvious that with such a production method, fishing has become prospecting for fish-rich regions of the oceans. However, prospecting for fish reserves is now an extremely complicated and expensive measure. This is explained first by the fact that the total area of regions for prospecting in the ocean is very large — more than 300 square kilometers. If information about fish habitats were to be collected from such an area, even if only once every two or three weeks, several tens of thousands of specially equipped vessels would be required. Spacecraft can resolve most of these problems.

There is no doubt that, in the near future, the application of space techniques for fishing will not only increase significantly the effectiveness of existing catch methods, but also introduce essential changes in these methods. The cosmonauts will play a large role in this work. It is also possible that oceanologists and ichthyologists — specialists in the study of the resources of the world's oceans — will be included in the crews of orbital stations.

The fact that almost all ocean products are concentrated in the surface layer to a depth of about 50 meters favors the study of fish congregation regions from space. The habitation conditions of food supply, water, temperature, etc., are most favorable for fish in this layer. It is well known, firstly, that the distribution of fish in the ocean depends to a significant degree on the state of the water /30
masses. The inhabitants of the ocean prefer those water layers where water masses of differing temperatures are in contact, and this is easily observed from space. Secondly, fish and other organisms excrete all sorts of waste products into the surrounding medium,

among which are specific fats which float on the surface of the sea and are sharply distinguishable by their spectra from the background of clean water. The detection of fish congregations in the open sea by the type of spectra can be comparatively simply and quickly organized with the application of spectrographic methods. Thus, since the spectra corresponding to different species of fish differ, it is possible to determine at once not only the location of fish, but also the species. This eases the work of fishing even more and yields additional economic benefits.

One can mention several types of work for the cosmonauts in the interests of national economy. Among these are improvement of mineral prospecting methods, the solution of unusual technological problems, and the accomplishment of some industrial processes. For example, under weightless conditions, it is possible to fabricate balls for bearings, among them even hollow, from any material and of practically perfectly spherical shape. Weightlessness and the absence of thermal convection on board an orbital station are unusually favorable conditions for producing a number of new materials in principle, such as foam steel and alloys of various metals with themselves and with nonmetals. There are great prospects in space for the production of lenses and mirrors of particularly high precision, for the preparation of particularly valuable drugs based on mixing various substances. New "space" methods and processes for processing various materials based on the use of electrostatic fields, capillary forces, and forces of surface tension, friction, etc., can lead to the creation, in a number of branches of industry (instrumental, pharmaceutical, metallurgical, chemical) of special "space" laboratories and workshops, beginning, obviously, on an extremely limited scale. One can consider the beginning of this as having taken place with the Soviet experimental device "Vulkan", with which cosmonaut V. I. /31 Kubasov accomplished vacuum welding of metals on board "Soyuz-6" in October, 1969.

Laboratory in Space

In the overall scientific research program for the study and utilization of space, an important and responsible role is played by experimental research performed directly in space. Experiments carried out by the cosmonauts on board spacecraft and long-term orbital stations are of great interest in this respect.

The ability of the researcher to move about in space does not indicate simply a widening of the sphere of scientific activity. A large number of problems as yet unresolved under terrestrial conditions can be solved with experiments in space. Weightlessness and the absence of the atmosphere contribute to this. In addition, new relations, phenomena and processes unknown on Earth are developed while carrying out research on board space laboratories. These new discoveries and results are capable, like a catalyst, of accelerating by many times the development of a number of scientific directions. For example, due to the opening possibility of performing experiments right in space, space physics, astrophysics, and radioastronomy have changed their appearance in a short time, and space biology and medicine have arisen.

The results of the flight of the long-term Soviet orbital craft "Soyuz-9" is representative in this respect. A large number of diverse problems were included in its flight program, among which, together with testing new forms of space techniques, were the following:

investigations of the possibilities of the crew to perform various tasks during long interaction with space flight factors and study of the readaptation process (transition of man from weightlessness for many days to terrestrial gravitational conditions);

accomplishment of a broad complex of scientific, technical, and medical-biological studies and experiments, and also further development of techniques in performing work in space in studies of the natural resources of Earth. /32

During the flight of "Soyuz-9", its crew performed more than 50 experiments using more than 60 different types of scientific apparatus. Each experiment was carried out in practice several times in order to obtain more reliable data. During flight, more than 1000 photographs of the Earth's surface, atmospheric meteorological formations, the daytime horizon of the Earth, atmospheric halo of its twilight horizon and water surface (photographs of various scales in black-and-white, color, and spectrozonal film) were taken and then transmitted to Earth. About 200 spectrograms of the atmospheric halo of the Earth and the underlying surface were obtained. Visual astronomical observations of stars, the Moon, meteors, and some planets were made [7].

On the whole, the data obtained by the crew of "Soyuz-9" is, in the opinion of representatives of the various sciences, of enormous scientific value, and is presently being studied with deep interest. In particular, the results of these investigations and experiments lead to more precise calculation of the altitude brightness profile of the horizon and atmosphere, improvement of data on the physical characteristics of space and the upper layers of the terrestrial atmosphere, deeper understanding of the possibility of man living and working fruitfully with long-term weightlessness.

The observations of A. G. Nikolayev and V. I. Sevast'yanov of the daytime and twilight horizon are very interesting. They analyzed in detail the haze effect which "washes out" the edge of the horizon, observed by all the cosmonauts in preceding flights. The cosmonauts noted that the color of the haze is not uniform, but depends on the lighting conditions and the degree of cloudiness. If the observation is made over the ocean when it is covered with clouds, the horizon over it has a whitish-greyish color, and if the sky is cloud-free, then the horizon is bright blue. Along the vertical, the color of the horizon changes from light blue to deep blue, then changing into the blackness of space.

During observations of the night and twilight horizon, the cosmonauts noted that a bright band, somewhat diffuse, is separated at /33

the edge of the horizon. At an altitude of approximately 115 km from the horizon of the Earth, they saw a bright luminous layer, grey in color with a slight pinkish hue — a thin luminous "torch". This phenomenon had not been observed by anyone before the crew of "Soyuz-9". It is of great interest to scientists, and the results of detailed studies carried out by Soviet cosmonauts of the characteristics and properties of this phenomenon have definite scientific value. The relation between the dimensions of the glow and the thickness of the "torch" was observed, the altitude of the "torch" above the night horizon, above the boundary of the twilight and night horizon, and the angular distance between stars and the "torch" were measured. The passage time was determined for stars lying in a plane from the "torch" to setting at the horizon of the Earth, and analogously for rising stars. Besides the discovery of the optical phenomenon, which they called the light "torch", A. G. Nikolayev and V. I. Sevast'yanov first observed two more effects. At the appearance of the first rays of sunrise, the dimensions of the space glow decrease abruptly, by about 30%, which can be explained by the physiological characteristics of the human eye.

The second effect was observed by the cosmonauts when the Sun rose above the horizon by about 10°. At this instant, a light areola appeared above the horizon, as if it had torn away from the surface and had withdrawn strictly along a tangent into the black sky. This effect, which the cosmonauts called the "moustache" effect, is connected evidently with scattering and refraction of light in the Earth's atmosphere [7]. The advantages of investigations of little-known phenomena by cosmonauts, compared with experiments on automated satellites, are quite evident in this example. The results obtained by man differ in the completeness of the data, the greater precision of the evaluation, and immeasurably deeper study of phenomena which the researcher encounters for the first time.

Analogous information could be presented about other scientific experiments on manned spacecraft — for example, astrophysical, biological, or medical. The greatest preference has been devoted to

these studies for some time in the cosmonaut flight program. There is every reason to assume that interest in these directions of scientific research on manned laboratory stations will be maintained in the following years. It is necessary to stress that, if the inclusion of medical and biological research in the flight program of manned craft is obvious, since to a significant degree the tests are made on the cosmonauts themselves, then the increasing interest in astrophysical experiments is explained by the extreme scientific urgency of the problems of modern astrophysics, whose solution provides great promise for extra-atmospheric methods of astronomical observations. The escape into space signifies a qualitative jump for astrophysics by which new results in principle can be obtained. /34

Such a judgment is based on the achievements in astrophysics over the last 20 years, when numerous notable discoveries (relict shortwavelength radio waves, quasars, pulsars, discrete x-ray sources, etc.) were made with new methods of ground-based observations (mainly radio-astronomical). The results of these discoveries produced an essential change in the concepts developed earlier in science about the structure and evolution of the universe, and about the laws of transformation of matter in the world around us. Since almost all these discoveries were made in proportion to the use of new means of observation and recording, one can expect that the application of extra-atmospheric astronomical devices placed on manned (and, perhaps, on automatic) spacecraft will bring new advances in modern science. In addition, understanding the processes occurring in stars will obviously solve one of the most urgent problems of modern life — the problem of energy. Explaining such a trend in modern physical research by the objective necessity, which is combined in physics, the well-known Soviet scientist L. A. Artsimovich has written: "If the stellar world is constructed somewhat reasonably, then the transition to the utilization of new space techniques for observations in the infrared, ultraviolet, x-rays and gamma-rays with the proper combination with traditional methods of optical and radioastronomy must lead in time to such an "information explosion" that we will be forced to again subject many of the most fundamental concepts of the structure of matter to radical reconsideration". [8]. /35

Thus, it is not by chance than an ever greater number of astrophysical experiments are included in the flight programs of Soviet manned spacecraft and stations, and the craft are equipped with more and more sophisticated and varied astronomical apparatus. Long-term orbital stations are especially promising in this respect. The great possibilities in the allocation of all kinds of devices and the presence of highly qualified research cosmonauts permit such a station to function as an actual extra-atmosphere astrophysical laboratory.

Some important data on the structure of the universe and on the characteristics of many objects in space far from us (quasars, pulsars, etc) can be obtained by recording the electromagnetic radiation from these objects. However, a large portion is absorbed by the terrestrial atmosphere. With onboard apparatus, the crew of a space laboratory can record soft x-rays from various celestial objects, study the spatial distribution of radiation of galactic and intergalactic origin, record infrared radiation from distant astronomical objects, and analyze the radiation spectra of these objects.

In these investigations, as in the investigations to determine the cosmic ionizing radiation, the main problem of the research cosmonaut is to develop the technique for performing the experiment, to adjust and control the instruments, to recognize the optimum operating mode of the apparatus.

The success of scientific observations by the cosmonaut also depends to a significant degree on the physiological characteristics of human vision under conditions of space flight. Data to date indicate great possibilities in this direction. V. I. Sevast'yanov wrote after his flight on "Soyuz-9": "If the Sun is not at the zenith, then in one illuminator the surface of the Earth is perfectly visible and one can recognize the continents by the landscape, and in the opposite illuminator the Moon, not far from it — Jupiter and next to it — Spica (Virgo) are visible in the black sky. On the day side, /36
one can identify Vega (Lyra), even when the spacecraft is turned.

Thus stars can be observed in the background of the day sky, but are difficult to identify without a star chart" [7].

The flight of American astronauts on "Apollo" spacecraft verified the possibility of human observation of the most diverse astronomical objects and at great distances from the Earth near the Moon. Thus, it was reported that the crew of "Apollo-9" observed Jupiter and four of its satellites (Io, Europa, Ganymede, Callisto) and followed telescopically the "Pegasus" satellite located at a distance of about 1600 km from the craft, and the launch stage of the lunar module of "Apollo" at about the same distance.

The great problems of space biology and medicine — the new scientific discipline — have been formulated in the last few years. Medical and biological investigations in space are quite varied. They are directed both at extending the problems connected with long-term human space flight and at studying the fundamental biological questions: the role of gravitation and various temporal cycles in the development of living processes in various organisms — from the simplest to human, the influence on the living organism of penetrating radiation, and other forms of cosmic radiation, etc.

At first, when the cosmonauts were required only to verify the basic endurability under space flight conditions, even if only briefly, medical experiments included mainly vestibular tests, psychological tests, and measurements of several of the most important physiological indicators — respiration and pulse rates. With increasing duration of manned space flights, the range of medical investigations has been extended, and the medical apparatus used for recording the necessary information has been improved. Very interesting results were obtained after the flight of the Soviet spacecraft "Soyuz-9", which indicated the possibility not only of long-term stays of man in weightlessness, but also his resourceful activity under conditions of extended space flight. /37

A large range of medical investigations were also carried out on the orbital station "Salyut". Multipurpose medical apparatus were

placed on it, including a multifunction medical device aiding the study of the adaptation mechanism of the human organism to weightlessness. It took electrocardiograms, measured arterial pressure, and evaluated the various phases of heart activity. At present, an automatic device for taking blood analyses during flight has been developed and successfully tested. A high-speed device for measuring the density of bone tissue has also been produced. Apparatus for measuring gas exchange, visual acuteness, muscle strength, etc., can be used on spacecraft.

However, in spite of the great successes of space medicine, many questions remain as yet unclarified. In order to affirm with certainty the possibility of manned space flights lasting several months, a whole series of medical and biological problems still have to be solved. Among them, the problem of creating artificial gravity is central. There are now various points of view about the necessity of producing artificial gravity on board manned spacecraft, but they are all only assumptions, until the physiological effects caused by weightlessness have been completely studied. For this reason, special tests and experiments to obtain the necessary medical data have been included in the manned flight program, particularly on the long-term craft and stations. Such investigations include, for example, taking electrocardiograms, recording various physiological indicators at rest and after measured physical stress, measuring the density of bone tissue, studying the changes occurring in the cardiovascular system and in muscle tissue, and performing psychological tests. Great attention is given in long flights to the state and evolution of microflora on the skin and hair and in the alimentary tract and respiratory organs. There is a fear that under the conditions of extended space flight, the state of the microflora can change in the direction /38
of increasing numbers of pathogenic microorganisms. Such a possibility is indicated, in particular, by the illness of American astronauts during the "Apollo" flights: Frank Borman with grippe and Russell Schweikert with indigestion. If the doctors' fears are verified, then the development of special means for preventing infectious illness among the crews of long-term spacecraft will be required in the future.

If in purely medical investigations the cosmonaut is not so much a researcher as an experimentee, then in biological experiments the role of the crew is more creative. Fairly many such experiments have already been performed. Various biological investigations were carried out in practice on all the Soviet craft, beginning with the "Vostok" series, and on the American "Gemini" and "Apollo" craft. The universal biological object — drosophila — was sent into space with Yu. A. Gagarin on "Vostok-1". P. R. Popovich experimented with drosophila and plants on "Vostok-4". V. F. Bykovskiy fixed vegetation on "Vostok-5". In 1970, A. G. Nikolayev controlled the light access to a test pilot of the unicelled algae, chlorella, on "Soyuz-9". Investigations on the rate and nature of mutations in drosophila, chlorella cells, and seeds of higher plants have been performed on the orbital station "Salyut". The technical equipment of the station performed experiments with great precision. Drosophila, whose reproductive characteristics under space flight conditions interested the scientists conducting this experiment, was placed in a specially designed thermostat in which the conditions excluded the effect of random factors. The participation of the cosmonauts in the experiment ensured the increased reliability of the results.

The goal of another biological experiment performed on "Salyut" was to study the development of swamp frog tadpoles from the egg, to investigate the effect of weightlessness on the development of the vestibular apparatus. Formation of the vestibular apparatus in tadpoles occurs in about four days. The cosmonauts took into flight with them fertilized eggs and from time to time, according to a developed technique, took samples of the eggs developing in weightlessness and fixed them with a preserving solution. The eggs were /39
delivered to Earth in this form for analysis by specialists. This experiment, simple in form, is an important link toward the overall goal of investigations of space flight factors, mainly weightlessness, on the development and functioning of living organisms at various levels, among them at the cellular level.

Similar experiments were performed by the American astronauts with sea urchin eggs.

The wide permeation of "space" investigation methods into the most varied directions of modern science, often transforming the face and broadening the content of these sciences, is one of the consequences of the scientific and technological revolution of our times. How revolutionary, as well as fruitful, the consequences of the "spacification" of the traditional science have been can be shown with, as an example, one of the most "earthly" sciences deeply connected with out planet and its natural resources — not only by its content but also by name — i.e., geology. The development of space techniques and the broadening possibilities of their application in the interests of scientific research has had a double effect on geological science. On one hand, an ever greater transformation of geology into a general planetary science is occurring, studying the general relationships of planetary structure and considering a planet as a single body consisting of gigantic geological structures, formations, and fractures. Geological research can be applied both for the study of the composition of space materials — lunar and Martian soil and materials of asteroids and meteorites — as well as for special geological or "planetological" surveys.

Methods to observe the Moon, Mars, Venus, and other planets from space have now been developed and successfully applied. Such surveys not only can reveal new details of planetary topography (for example, craters were observed on Mars, analogous to those on the Moon), but also serve the practical goal of space science by giving more precise data about a planet before landing apparatus on it. Thus, before the American "Apollo" carried astronauts to the Moon, a detailed photosurvey was carried out of the landing sites with automatic and manned craft flying around the Moon. This new direction of geology, or, more precisely, planetology, is very important /40
for the study of planets. The first samples of lunar soil fell, not by chance, to geologists to study its composition. Among the scientific equipment of the astronauts visiting the Moon, an important role is played by geological instruments — boring apparatus, geology pick, a special scoop for collecting rocks, seismometers, etc. It is possible that special branches will appear in geology, together with the "general planetary" direction, which will be devoted to individual

the "general planetary" direction, which will be devoted to individual celestial bodies — selenology, marsology, etc.

Another aspect of the effects of space science on geology is connected with the possibilities of observing the Earth and its geological and geographical objects from space with automatic artificial satellites and manned laboratories. This is also unusually promising and very attractive in practical respects, since it serves as a basis for producing new methods in principle for discovering reserves of minerals and other natural resources on the Earth. Of course, it is still early to talk about all the geological problems to be solved by methods of observation from space. However, interesting data have already been obtained. Some previously unknown effects associated with processes occurring in the interior of the Earth and connected with the formation of the Earth's magnetic field and other structural anomalies of our planet have been discovered with space methods.

Scientists consider the information obtained from orbital craft and stations to be very valuable for the study of tectonic and morphological structures of the Earth, for the determination of the interrelation of geological macroelements and for the study of the motion of the Earth's crust and the form of the rocks in it. Data obtained during flights of Soviet cosmonauts have made a significant contribution to the development of terrestrial geology.

Of course, in principle, geological photosurveys of the Earth's surface can also be made from automated satellites. But this is not always effective. In the first place, the surface of the Earth is frequently covered with clouds. If the satellite photographed continuously, then a large fraction of the photographs would be unsuitable for geological analysis. Since the film supply on a satellite is limited, it would appear that too little useful data would be collected during its flight. If it is specified that only the cloud-free surface is to be photographed, then the automatic equipment of the satellite is more complicated and, consequently, its reliability decreases. /41

Figure 6. Group of Soviet cosmonauts at the V. I. Lenin memorial in the Kremlin.

From left to right: V. A. Shatalov, V. V. Gorbatko, V. N. Kubasov, A. V. Filipchenko, V. N. Volkov, P. I. Belayev, G. S. Shonin, G. T. Beregovoy, and A. S. Yeliseyev

Man on board an orbital station can solve this problem very simply. He will select the most suitable parts of the Earth's surface for photographing. He ensures the best quality of photographs by selecting the optimum modes for photographing. In addition, the advantage of man over automation in these studies includes the fact that he can use the same photoapparatus for different purposes. For example, photosurveys of such mountain regions as the Pamirs, Caucasus, and Himalayas are of interest not only to geologists, but also glaciologists, hydrologists, geodesicists, and cartographers. The /42
definite form of the photograph — its scale, spectral region and size — will be of the greatest value for each specialty. To assign a whole set of requirements to automation is not always possible because of design, weight, or other limitations. Man can repeat the survey of the same proportions under different conditions to ensure photographs of the greatest value.

Ever greater possibilities will be open to science, when scientists can be included in the station crew. Then research

geologists on board an orbiting laboratory will have unique conditions for performing systematic and comprehensive studies of the Earth's structure, and for improving methods of mineral prospecting. Geological experiments were introduced in the flight programs of the "Soyuz" series and in the "Salyut" station programs. Photosurveys of geological formations on the eastern coast of the Caspian Sea were carried out as early as 1969 from "Soyuz-6", "Soyuz-7", and "Soyuz-8". After a year, V. I. Sevast'yanov on board "Soyuz-9" took a large number of photographs of geological and geographical objects in regions of southern European USSR, Kazakhstan, and western Siberia.

In addition to the scientific disciplines considered above, in which some experience in the application of space techniques has already been acquired, there are many divisions of physics, chemistry, and other fundamental sciences where scientists have become ever more interested in the possibilities to be revealed with the performance of experiments beyond the Earth.

It is still difficult to fully evaluate, or even suggest, the consequences of similar investigations. Evidently, many of the investigations will occupy a place for a long time in the flight programs of space stations. In any case, there is no doubt that future cosmonauts in the crews of orbital scientific stations will have varied, difficult activities very necessary for science.

Tests of New Technology

Along with the scientific and technical investigations and experiments which the crews of spacecraft have performed in flight, /43
they have also been responsible for retesting new or improved instruments, systems, and mechanisms. Developing methods and procedures of operation with apparatus in space, timing the performance of separate operations, and evaluating the optimization of cabin and control panel designs are also included in this problem area.

The crew of a spacecraft begin to take part in tests long before the space flight. This is because both the individual instruments and systems, as well as the spacecraft or station as a whole, pass several test cycles in the factory shops and in laboratories. The work of the cosmonauts is such that they themselves are the operators performing the tests. Each member of the crew performs tests mainly on that apparatus with which he will have to work during space flight. Thus, already at the testing stage some specialization among the crew members appears, which is maintained in the subsequent stages of preparation.

The crew also takes part in operations performed on models of consoles, cabins, and control posts. Before the working drawings of objects are produced, simulation is undertaken to obtain the optimum arrangements and the optimum design solutions. Comparison of the different design solutions is made with models, after which the best one is selected. The crew also participates in the ground testing of flight equipment: flight suits, standard and loaded, medical sensor systems, ground emergency supply units, and in testing the quality of onboard food, drinking water, personal and toilet articles.

The crew participates in the complex tests of the spacecraft in the final stages of its preparation. These tests have as their purpose the ground "loss" of several flight situations, during which all the systems actually function, and a multiple simulator creates /44 the complete illusion of an outer space environment. During this time, the crew is inside the craft at their stations, and perform all the same activities which they will perform during actual flight.

While conducting all the tests enumerated above, the crew members watch attentively for the accuracy of equipment functioning, report their observations, and also acquire experience in working with the equipment, they deepen and broaden their skills, and become acquainted with possible failures of the equipment.

The space flight itself is, in essence, also an operational test stage, since present space technology is of an experimental,

not a commercial, nature. Under conditions of space flight, the crew continues to perform tests of space technology. The special job of research engineers was introduced for this on the orbital station "Salyut"; a more detailed account of this will be given in the next section. However, one should not think that only the research engineer is occupied with test operations and that his function is limited to this. All the crew members are to some degree testers, and they all participate in the flight control.

An especially large volume of tests was performed during the flight of the orbital station "Salyut". The crew of the "Soyuz-10" spacecraft, and later of "Soyuz-11", worked mainly with techniques not applied previously in flight. The flights of these craft can be called test flights, although a large volume of tests was also performed during other flights of the "Soyuz", "Voskhod", and "Vostok" series.

After completion of the space flight, all the results of test operations are delivered by the crew to Earth in the form of movie films, entries in onboard journals, recordings on magnetic tape, and also in the form of samples and specimens. These materials are thoroughly processed by scientists and engineers, appropriate reports are compiled and conclusions are drawn. Then, these materials /45
will be used for the preparation of subsequent flights, and are a necessary condition for creating a reliably operating space technology.

Crew of the Scientific Space Station

The flights of the "Vostok" series of satellites should be con- /46
sidered as the greatest triumph of Soviet manned cosmonautics. The crews of these craft — from Yuriy Gagarin to Valeriy Bykovskiy — have written a glorious page into the history of cosmonautics. The test nature of the flights stamped itself on the design of the craft as well as the composition of the crews. All the "Vostok" craft are

Figure 7. Cosmonaut N. N. Rukavishnikov testing new technology before flight

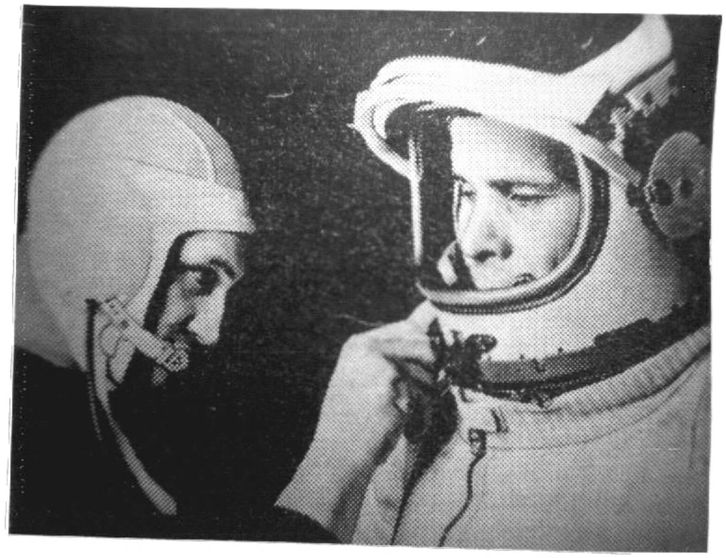

Figure 8. B. V. Volynov and A. S. Yeliseyev in training

one-man, controlled, as a rule, by experienced pilots who had entered cosmonautics from aviation. At that stage of space conquest, this was the most proper solution to the problem, and is not explained at all by the "load capacity" of the "Vostok", not permitting an increase in the number of crew members: the "Voskhod" type craft, whose flights took place later, were three- and two-man, although they were to a significant degree modifications of the "Vostok" class craft. As already noted above, at the first stage of man's conquest of space, man himself along with the other systems of the spacecraft was passing flight tests, so to speak. The tests performed showed that the professional pilot, after special preparation, is sufficiently adequate to withstand the conditions of space flight.

But this was not enough. It was necessary to establish whether a man not having professional pilot training could also work successfully in space. Such a test was first undertaken in 1964 with the flight of the three-man spacecraft "Voskhod" whose crew included, in addition to commander colonel engineer V. M. Komarov, also a scientific worker, candidate of technical science K. P. Feoktistov, and a doctor, B. B. Yegorov. Both crew members — doctor and scientific worker — had no professional flight training, and passed only

special medical selection and, to the necessary extent, preflight preparation at the cosmonaut training center. The whole course of the "Voskhod" flight and postflight analysis showed that all the crew members withstood the conditions of space flight well. Thus, it was established that, with proper medical selection and subsequent /47 special preparation, representatives of various specialties can work under conditions of space flight. This fact had very great significance: the complexity of space technology was increased, the role of man in the control of spacecraft was increased, ever greater and greater numbers of scientific experiments could be performed during flights. One pilot was no longer able to perform all the planned program and to attend to the operation of the multiple and complex onboard systems. The presence of an onboard engineer was required, who could attend the operation of the systems, be responsible for the accuracy of their operation, and find solutions in case a failure occurred. Candidate of technical science A. S. Yeliseyev on "Soyuz-5" was designated as the first onboard engineer. However, even before him, cosmonaut K. P. Feoktistov on "Voskhod" filled the role of onboard engineer. Subsequently, the well-known consmonauts V. N. Kubasov, V. N. Volkov, V. I. Sevast'yanov, and one of the authors (N. N. Rukavishnikov) worked in the role of onboard engineer. All of them had many years of experience in industry, and were experienced and qualified engineers before entering the cosmonaut ranks.

Thus, the pilot-craft commander, whose function is to pilot the craft and who carries the responsibility for completing the flight program, and the onboard engineer formed the crew, who ensured the flight and functioning of the spacecraft systems. In addition, both crew members performed a definite volume of scientific investigations and experiments for the given flight.

However, with the increasing number of experiments to be performed, the necessity appeared of adding yet another crew member who would take on the main part of the scientific and experimental work in the flight. This third crew member received the designation, research engineer. Thus, for example, cosmonauts Ye. N. Khrunov on "Soyuz-5" and V. V. Gorbatko on "Soyuz-7" served as research

engineers. The introduction of a research engineer into the crew was a qualitative jump in solving the problem of spacecraft crew formation. Crew formation took place somewhat differently for work /48
with the program of the orbital scientific station "Salyut", which carried a large quantity of new systems, new equipment, new scientific instruments and devices. The same can also be said about the "Soyuz" craft which played a transport role for servicing the "Salyut" station. The majority of the new systems had not been operated in space before and, thus, there was the problem of performing special flight tests of the new equipment. For this, a new job was introduced into the crew — the job of test engineer. Several experienced engineers having many years of experience in industry were prepared for working in this job. Among them was Viktor Ivanovich Patsayev, who carried out the flight tests of the new systems on board the "Salyut" scientific station over a period of 23 /49
days, and performed numerous scientific experiments with the other crew members.

Figure 9. Cosmonauts V. N. Kubasov, A. A. Leonov, and N. N. Rukavishnikov practicing stellar observations

One can mention in summing up that at present the crew of a spacecraft or station has, as a rule, a fixed nucleus consisting of a pilot commander and an onboard engineer. In addition, cosmonauts performing various flight assignments are included in the crew. It is important to note that crew preparation is conducted so that each of the crew members can replace any other and perform his work. The contemporary cosmonaut must be, if one can express it thus, universal.

How do we imagine crews in the future? Of whom will the crews of multi-manned orbital stations and interplanetary spacecraft consist? It seems to us that cosmonauts from two categories will be included in these crews: command crew handling the flight and a group of specialists performing the tasks of the given craft. Pilots, onboard engineers, navigators, communications specialists and doctors should be included in the first category. These specialists should ensure the launch of the craft, its flight in orbit, all the necessary space maneuvers, and arrival of the craft in the assigned region, maintaining conditions on the craft necessary for personnel operations and ensuring the high reliability of onboard systems by preventive operations and repair. Specialists performing work for the purpose of the flight are included in the second category. This picture is, without a doubt, very approximate. Real life will bring significant changes in proportion to the complication of the purposes and problems before cosmonautics.

Preparation of Cosmonauts for Flight

Control of contemporary spacecraft in flight, performance of scientific and technical experiments, carrying out preventive operations — all these are extremely complicated operations requiring great and versatile preparation of the crew. The following principle /50 is usually adhered to in compiling the crew preparation program: each crew member must be able to control the spacecraft, to service the regular systems of the craft, to carry out such operations as maneuvers of the spacecraft, descent from orbit to Earth. On the other hand, each crew member must be specialized in some direction in order to have the possibility of investigating more deeply the problems which he will solve in flight. However, this specialization assumes any crew member must be in condition to perform any programmed work in flight. Thus, the quality of the performance will depend on the specialization of the cosmonaut.

The construction of a preparation program by such a principle leads to the fact that the contemporary cosmonaut must be a specialist of a broad profile, having solid knowledge about a large number of disciplines from medicine to astronomy. In addition, there are a number of questions which the cosmonaut must know exactly and a number of operations which he must be able to perform sharply, automatically. These are mainly questions concerning the devices and functioning of the important life systems of the craft and the control operation by the craft and its systems at various stages of the flight. In connection with this, the flight preparation of the cosmonauts occurs in several stages. First of all, there is the so-called general space preparation which is conducted with personnel who have not participated previously in space flight preparation. This concerns preparation in such disciplines as mechanics of space flight, space navigation, general principles of the spacecraft, mechanism, astronomy, geography, meteorology, space biology and medicine, etc. As a rule, preparations are carried out in the form of lectures and practical experience, with subsequent passage of examinations.

The next stage of preparation is the so-called technical preparation. This stage begins after crews are formed for work on a particular program, for example, on the program of the orbital station "Salyut". At this stage, the future flight participants become acquainted with the material. The studies are in the form of lectures and seminars, and are conducted by leading specialists in the /51 various spacecraft systems. In addition, practical studies are conducted with the cosmonauts at enterprises fabricating the separate assemblies and instruments of the spacecraft, at assembly shops, at test stands and test areas. The future space flight participants take part in the design of systems, the compilation of flight programs, onboard flight documentation, and are present at technical conferences. This stage of preparation is also concluded with examinations.

At the same time, the crews study so-called space flight preparation. Here studies are related to various types of trainers and test stands simulating future space operations. As an example of

such test stands, one can cite the manual craft orientation stand simulating the dynamics of spacecraft motion by means of an analog-digital computer complex, or the stand for manual control of the approach of a transport craft to the orbital station. The number of test stands on which flight preparations are carried out can reach several dozen. The space flight preparation stage should include training flights on aircraft, parachute jumps, working out crew activities after the spacecraft landing on ground or water under various climatic conditions. However, the basic form of study in the space flight preparation stage is training on the so-called complex trainer. This installation is an exact copy (model) of the spacecraft for the flight on which the preparation is intended. On this model of the craft, simulation of all the control, signal and indicator systems, and simulation of the space environment around the craft are provided. The one at the cabin controls in this trainer can observe the Sun, the stars and the Earth's surface in the cabin illuminator. Engaging the manual orientation system, for example, and turning the position control knobs, all the objects observed in the illuminator begin to move from the same positions and with the same speeds as would occur in actual flight. During studies on space, /52
the crew work out all the basic operations to be performed in flight, from launch to landing of the spacecraft.

The medical and biological preparation of the cosmonauts should be considered separately. Regular periodic medical examinations, training on special stands, determination of the behavior of the organism to uncomfortable conditions and special medicinal preparations are related here. One should also include here crew preparation to work with special means permitting endurance of space flight conditions over long time periods. Such means, for example, are various types of loaded and training suits, running track stands, means of personal hygiene. In addition, it is necessary to study methods of self- and mutual aid, and also onboard recording medical apparatus and radiation dosimetry control apparatus. The crews also pass examinations for this section of preparation. For the duration of all the stages enumerated above, the crews go through increasing

physical preparation. Its basic purpose is to ensure the harmonious development of the entire human system: trained muscles, sufficient endurance, sound hearts, and a high mental volitional quality. This form of preparation is carried out by experienced gymnastic instructors at special sports centers having all the necessary equipment.

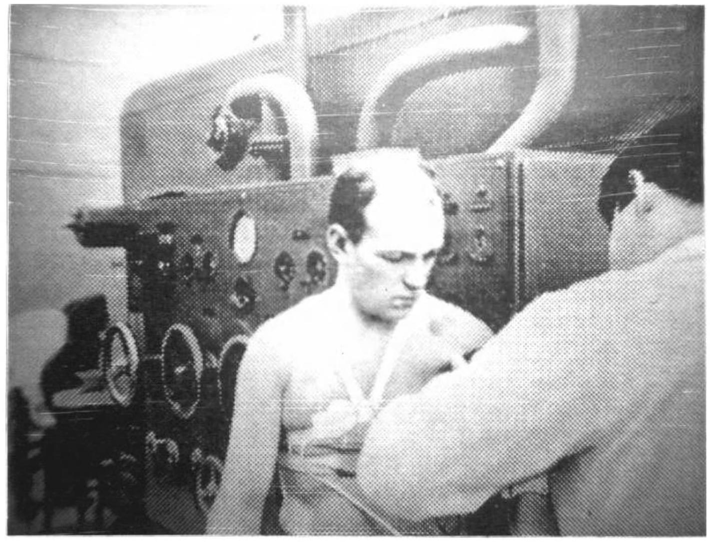

Figure 10. Preparation for medical tests in pressure chamber

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In conclusion, one more important stage of preparation should be discussed — preparation for performing scientific and technical experiments and investigations in flight. This stage is an extremely significant object of study. For example, about 100 scientific experiments were performed on the "Salyut" station. If one considers that almost every such experiment has its own apparatus, program, and performance technique, then the whole extent of the preparation which is necessary for the cosmonauts to go through in order to study all the experiments becomes obvious. At this stage, the cosmonauts have close contact with the scientists who have worked out these experiments. The cosmonauts study on learning devices and stands, attend lectures, leave for preparation at various scientific organizations, spend much time in observations at various observatories, take part in compiling and formulating the onboard operational documentation.

And finally, at the conclusion of all the preparation the crews pass the following test — the so-called complex examination training. This training is conducted on a complex trainer, lasts several hours or tens of hours, and includes performance of all the main stages of flight, i.e., the flight is played back on Earth in its main stages. The flight conditions are simulated as completely as

Figure 11. Crew of "Soyuz-10" space craft, A.S. Yeliseyev, V.A. Shatalov and N.N. Rukavishnikov.

possible, except weightlessness which cannot be created on Earth. Performance of this training flight is controlled by the state commission on whose instruction various types of inaccuracies simulating /55 possible failures in flight can be introduced into the normal operation of the trainer. The crew is obliged to record these inaccuracies, locate, and find means for controlling them.

After successfully completing the complex examination training and after passing examinations in all the necessary disciplines, the state commission judges the preparedness of the crew and its clearance for space flight.

It is evident that, since the present extent of preflight preparation for cosmonauts is extremely great, only thoroughly prepared, physically developed, well-trained specialists of a broad profile can successfully cope with it. However, there is no doubt that in the future, with the improvement of space technology and with easing of

conditions of spacecraft activity, not only professional cosmonauts, but also scientists of various narrow directions, will be able to participate in space flight. Then, evidently, the extent of pre-flight preparation will be reduced, and the composition of preparatory studies and training will be changed.

A View Into the Future

Manned space facilities will, evidently, be developed along three main directions: long-term orbital stations, multi-man bases for thorough study and utilization of the Moon, and long-range spacecraft intended for expeditions to Mars, Venus, and other planets of the solar system. We will conclude our narrative with a short survey of these directions.

Orbital base stations. The launch of the Soviet long-term orbital station "Salyut" in June, 1971, signaled the beginning of a new stage in the development of cosmonautics — the stage of the utilization of circumterrestrial space and the thorough investigation of Earth from space. Academician B. N. Petrov has said that, if the possibility of human flight into space and work there was shown in the first decade, then the second decade will be a period of system- /56
atic investigations with the help of orbiting space laboratories. Actually, it is impossible to proceed to the utilization of the Moon and deep space without solving a number of immediate "terrestrial" problems and without creating and developing new examples of space technology in circumterrestrial orbits.

It is obvious that both the Soviet orbital station "Salyut" and the American station "Skylab", launched into orbit in May, 1973, are only a few of the first steps to the conquest of circumterrestrial space. Future orbital stations will be quite unlike contemporary spacecraft. First of all, they will be multi-man. Their crew will consist of a command crew maintaining the onboard service systems and providing necessary maneuvers, and groups of specialists

solving scientific and national economic problems. The command crew of the station, besides the crew commander, will include 2 - 4 engineers, specialists in electronic systems, life support systems, radiotechnicians, and the other onboard systems. In addition, it is possible that a doctor will be included in the crew to perform medical examinations and to render necessary aid. The scientific group, headed by a scientist-director of the whole scientific program, will include 10 - 15 specialists in various branches of science and the national economy. At first, the functions of crew commander and scientific director of the flight will be performed by one person, who remains on the station; the remaining crew members will change. The relief rate will vary for the different specialists.

The outward appearance of the orbital station will change in comparison to present craft. There will be several separated rooms, each being an independent laboratory: medical and biological, astronomical, technological, meteorological, etc. Research cosmonauts will perform planned experiments in these laboratories, either personally, or with the help of automatic scientific apparatus for whose maintenance they are responsible. It is assumed that special living quarters with sleeping rooms, crew stateroom, and living rooms will /57 be built into the station for rest, sleep, eating, and performing hygienic and physical cultural procedures. Thus, the future orbital station will perform the functions of a space science center, having separate experimental laboratories and installations. Some laboratories can be completed in the form of separate independent modules which can depart from the main base-station, move to another trajectory, and return to base after completing the specified cycles of tasks.

There can be not only scientific laboratories, but also technical and even technological modules in the orbital science center. Thus, one of the modules could be adapted for developing and testing units, systems, and, perhaps, even whole sections for prospective spacecraft, for example, interplanetary. Fitting the test module with sophisticated measuring techniques and participation of

experienced test engineers in the testing will significantly accelerate the finishing process for new space systems to the necessary high quality, and eliminate the necessity of systems testing by other manned craft.

It would also be suitable to have in orbit a manned module in which investigations could be carried out to determine the optimum conditions for utilizing space techniques and periods for carrying out preventive and control operations.

A fixed scientific station in an Earth orbit will ensure direct participation of many scientists in the investigations, since the teams of specialists can be repeatedly renewed. With the help of transport craft, the scientific equipment can be replaced, the supply of products, technological materials, photo- and movie film, etc., can be replenished.

There is no doubt that, to maintain a high level of research, the professional cosmonauts will also be replaced by backups and will be sent to Earth for rest. It is probable that the time will come when all cosmonauts will begin their practice of space operations on /58
orbital stations as backups for the main command or as trainees.

Lunar bases. Long-term lunar bases will be created on the surface of the Moon for solving the problem of its utilization. Only processing of observation materials, preliminary study of lunar soil samples, communications with Earth, and rest will take place on the base. The main work of cosmonauts on the moon will be to carry out geologic, geodesic, and cartographic surveys, and to study the soil and the structure of the lunar surface. In addition, astronomical observations of the Earth, Sun, and other celestial objects will be included in the study program at the lunar bases. Observations of the Earth from the moon will supplement significantly the data obtained from orbital stations. Both ordinary astronomical devices, as well as radiotelescopes on the surface, can be used for this.

Besides scientific investigations, the lunar base crew will have to work on the construction of various facilities on the surface of the Moon. Initially, the construction material will come from Earth in the form of assembled constructions and pellicular panels. It is assumed that wide use of inflatable construction will be found in the lunar facilities, since the durability requirements on the moon are significantly less in view of the smaller force of gravity, compared to Earth, and the absence of wind and other loads connected with an atmosphere.

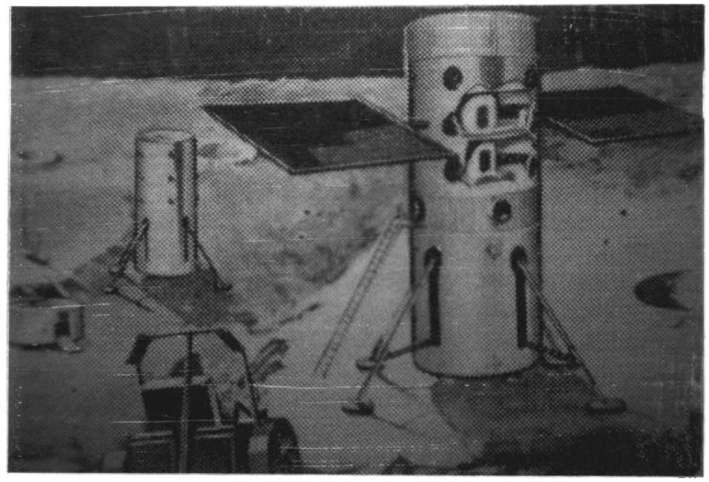

Figure 12. Plan of long-term multi-location lunar base (USA)

Later, lunar soil can be used as a construction material, either in its primitive form or after suitable processing (fusing, sintering, etc.).

The first lunar settlements will be organized, evidently, like arctic and antarctic stations. Their crews will consist of specialists of three groups: command crew maintaining the base systems and providing transportation for the personnel from the Earth to the Moon and back, construction assemblers, and scientific workers performing the scientific program.

The constructive solution of lunar bases is impossible to pre- /59
determine now. There are, for example, various projects described in the foreign literature: 1. A monomodular multi-man base with 10 - 20 man crew and multiple automatic lunar stations periodically visited and serviced by base personnel. The lifetime of such a base is 1 - 2 years. 2. A base consisting of several small manned stations with 2 - 3 man crews and a lifetime of 2 - 4 months. After

completion of operations, the crew of each station will return to Earth and the station itself will be preserved and will be uninhabited, or will be visited by crews of other stations. The scientific equipment remaining at the station will continue operating automatically. 3. A base sunk into the lunar soil. Evidently, there will be several small stations at first, and later multi-man bases will gradually be formed.

Since the main activity of lunar base crews will be performed beyond its limits, automatic life-support systems must be given great consideration in the planning.

The simplest solution, used in the American "Apollo" program — the creation of pressurized suits with an interchangeable back pack life-support system — imposes limitations on the distance which the cosmonauts can move away from the base and on the whole operating time, since it is impossible to wear pressurized suits for a long time. There are other methods — for example, the use of lunar vehicles with pressurized cabins in which a fixed life-support system is placed. The cosmonauts in the cabin of a lunar vehicle could study wide areas ranging from base 100 - 200 km. Operations in soil boring, seismic experiments, and sample collection could be performed without leaving the cabin by using remote manipulators. In a critical situation, a rapid egress from the lunar vehicle in a light pressurized suit can be accomplished. It is interesting that in several projects, lunar vehicles with air cushions and lunar flying machines with rocket motors are proposed for use, instead of lunar vehicles with wheeled or caterpillar tracks. Calculations show that because of the small gravitational force on the Moon, such apparatus could have a greater range than ordinary lunar vehicles, and in a number of cases would be more economical. /60

Interplanetary craft. The organization of an interplanetary expedition is a problem of significantly greater difficulty than the creation of orbital and lunar stations. Thus, the accomplishment of such an expedition is a matter for the distant future. A number of

complicated medical, biological, and technological problems have to be solved before spacecraft will be created which are sufficiently reliable to ensure safe manned flights for several years, and with the weight characteristics acceptable for present carrier rockets. In view of the great duration of interplanetary flight, the main problem will be that of ensuring the health of the cosmonauts. Problems of protecting the crew from the fatal effects of cosmic rays and of creating an artificial gravitational force on board the craft must be solved first of all. Developing methods for solving these problems will be carried out on orbital stations.

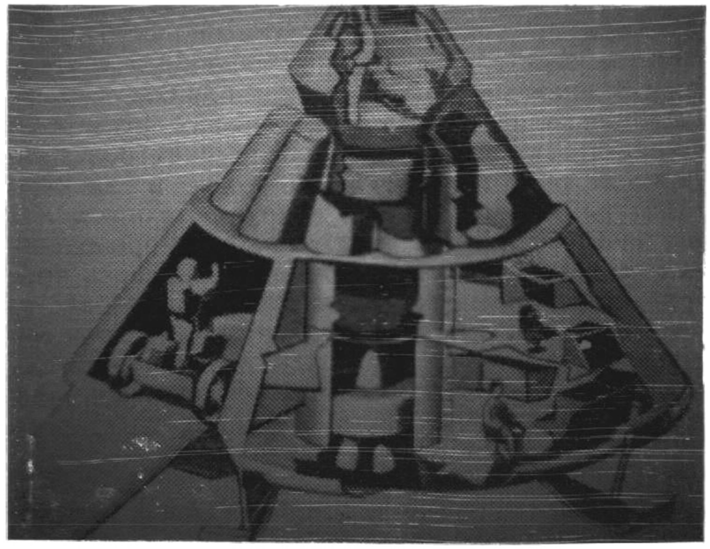

Figure 13. Plan of craft for expedition to Mars with landing on the planet (USA)

The crew of the first interplanetary spacecraft will be small — 4 - 6 persons. The main problem of the crew in flight will be to ensure the efficiency of all systems, and after landing on the destination planet — to perform the assigned program of scientific investigation. During flight, besides maintaining the craft, the crew can also solve various scientific problems, although the abundance of scientific apparatus for these purposes will, evidently, be quite limited on the first expeditions. /61

The first planet to which an expedition will be sent will probably be Mars. The opinion of almost all specialists is unanimous in this question. The nature of cosmonaut operations on Mars is analogous to operations on lunar bases (surface studies, soil sample collection, cartography), with the only difference being that the

physical conditions on this planet differ as much from lunar as from terrestrial, and the cosmonauts can find the most unexpected phenomena.

To protect the crew from cosmic radiation, various methods of radiation shielding for the cosmonauts are being developed by creating around the craft a plasma cloud of strong magnetic or electric fields, weakening the effect of cosmic radiation in the living compartments of the craft. /62

Besides developing means for creating artificial gravity and radiation shielding, the most important technical problems will be problems of onboard power and flight control, problems in developing highly efficient long-term life-support systems, transmission of possibly great volumes of scientific information from the craft to Earth, and others. But the most serious problem will be, indisputably, to provide high reliability of the onboard systems. The crew will play the central role in maintaining the whole assembly on the interplanetary craft in a state of constant efficiency. The cosmonauts will have to have faultless knowledge of all the characteristics of the craft devices and its systems, skill to quickly find and replace defective units, and in a number of cases make necessary repairs themselves. Highly qualified, well-educated specialists having space flight experience will be included in the crew of interplanetary craft for the successful accomplishment of the expedition tasks on other planets. They must not only understand the electronic apparatus, computer, and other techniques which the craft will contain, but also have experience in performing scientific investigations in order to successfully complete the operational program on the destination planet. In the preparation of interplanetary craft crews, such factors as moral volitional qualities and the psychological compatibility of the crew members will be of important value.

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